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FIRST GENERATION

FUEL SYSTEM DESIGN

TE-87-11

DISCLAIMER

This study was carried out with the cooperation of the Department of Energy, Mines and Resources. However, the views expressed in the report are those of the author and do not necessarily reflect the views of the Department.

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ABSTRACT

The design and installation practices of first generation natural gas fuel systems were reviewed. The safety problems of current systems were analysed. Short term solutions were suggested in which the aim is the reduction of the number of parts, safe routing of fuel lines and relocation of the refuelling port. The long term design featured a restricted high pressure area with integrated components, special fittings and less restrictive components.

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1.0 INTRODUCTION

1.1 Background

Canadian government interest in natural gas as a transportation fuel began in 1980, when the B.C. Ministry of Universities, Science and Communications awarded research contracts to B.C. Research and the Mechanical Engineering Department of the University of British Columbia.

This interest was generated by the success of natural gas vehicles (NGV's) in New Zealand, where the government was aggressively promoting the use of domestic rather than imported fuels. CNG had also been successfully used in Italy for forty years. Dual Fuel Systems, a division of the Southern California Gas Company, had been experimenting with CNG since 1969. They were manufacturers of conversion equipment used mostly on the Gas Company's fleet.

In 1981, as part of the National Energy Policy, the Federal Ministry of Energy, Mines and Resources began funding R&D for natural gas as a transportation fuel. Simultaneous to Canadian government involvement, CNG Fuel Systems started their operations in Calgary. Initially, they imported Italian regulators and manufactured mixers to adapt the systems to larger American engines. Eventually they developed some of their own conversion equipment.

Soon a variety of Italian and American products were imported and the choice of conversion equipment grew. Further into the 1980's the number of NGV installations increased. Installation procedures were mostly inherited from experienced converters like Dual Fuel Systems.

Modern installation practices vary among shops. The conversion parts are commonly drawn from either Italian and New Zealand manufacturers, Impco, Eco, Mogas or CNG Fuel Systems. Although parts specified by Canadian safety standards are common to every installation, variations arise in their location and the way they are linked. Some procedures are based on poor engineering practices but have existed for so long that their validity is not

questioned. Unfortunately, competition in the conversion market dictates that less expensive and less safe installations will prevail until regulations are enforced more strictly.

These practices can lead to potentially dangerous fuel systems. There is a need for improvement of the present fuel system design and installation. Better engineered parts and practices will mean safer and more reliable systems and, consequently, increased user satisfaction.

The scope of this project was to produce a theoretical design of an optimal natural gas fuel system. The project team gave special emphasis to reducing the number of connections in the fuel system and ensuring that installations are simpler and safer.

1.2 NGV Regulations

The Canadian Gas Association has developed regulations pertaining specifically to natural gas vehicles. The CAN1-12.3-M84 covers NGV Fuel System Component specifications and sections 9 and 10 of the CAN/CGA-B149.1-M86 Natural Gas Installation Code specify installation procedures for vehicle conversions and refuelling stations. These regulations are based on common safety practices, research and experience with NGVs. Where there is common ground with established codes and regulations, the CGA NGV codes refer to them.

The provincial governments are responsible for enforcing regulations. Because of the large number of vehicles operating on natural gas in B.C. and Ontario, these provinces have established procedures to enforce NGV regulations. In B.C., Ontario and Quebec, NGV equipment installers must take a course and obtain a license to install and service natural gas fuel systems. In the Prairie Provinces, where the number of NGVs is relatively small, procedures are presently being set up.

Since the provinces regulate natural gas vehicles locally, the CGA codes are not enforced uniformly across Canada. In addition, there is some discussion regarding which codes to enforce, especially concerning storage cylinders. For the scope of this project, however, the CAN/CGA codes exclusively apply.

Some gas utility fleets have their own stricter standards for conversion installations on private and company owned vehicles [1]. These practices lead to more reliable and inherently safer conversion systems .

2.0 FUEL SYSTEM REQUIREMENTS

2.1 Functional Requirements

The basic elements of an NGV fuel system are:

- high pressure storage
- refuelling sub-system
- engine fuelling sub-system
- piping network

2.1.1 Equipment

Most NGV systems used on twin-fuel vehicles have the storage tanks in the rear (trunk or cargo area) and the majority of the fuel system components under the hood. Each tank is equipped with what is commonly referred to as a 'tank valve' incorporating a 3-way shut-off and a pressure relief device. In earlier conversion systems, the refuelling port and back check valve were connected to the fuel line by a tee fitting near the front of the engine compartment. A manual shut-off valve was located near the refuelling port or near the tanks to isolate the storage tanks from the remainder of the fuel system. Recent systems use an NZIG master shut-off valve which incorporates the refuelling block and pressure gauge thus eliminating the need for a tee fitting. The refuelling block usually incorporates a pressure relief device. According to the B149 code, the fuel lines must be made of a material resistant to corrosion and the chemical action of the gas. In most cases, stainless steel lines are used although it has been reported that carbon steel lines are being used on certain conversions [2]. Compression fittings are used to connect the fuel lines together while pipe threads in stainless steel or brass are utilized for screw-on fittings. The pressure regulator, a device to reduce the gas from the 20 atm. (3000 psi) tank pressure to the mixer/carburetor feed pressure, is mounted in the engine compartment with a short low pressure line leading to the mixer/carburetor assembly. The dual curve ignition module, used to permit advanced spark timing for NG, is found either on the firewall or under the dashboard. See Figure 1 for a typical early fuel system layout.

2.1.2 Safety

Safety is a key functional requirement. Reducing the potential for leaks will improve the safety of the existing system. This can be achieved by reducing the number of parts, insuring a better seal in connections and confining high pressure lines to a limited area. Fuel system components should also be relocated to areas protected from direct impacts or harsh environments. Finally, the refuelling system must enable a safe one way passage for the gas.

2.1.3 Simplicity

An optimised system design will enable easier installation and repairs. Problems such as leaking seals should be eliminated either by simpler designs or better installation guidelines. Through better design, unnecessary or redundant parts can be eliminated. In addition, simpler, more reliable systems will lead to better public acceptance of NGV.

2.2 Safety Guidelines

The proposed fuel system design adheres to the established Canadian codes and standards for refuelling pressures, product specifications and installation practices. When the design deviates from the code, justification is given.

Different types of vehicles will offer different constraints. For this reason, some of the suggested practices will not be totally workable. In the design, differing vehicle types have been considered as much as possible in specifying new components or practices.

2.3 Scope of the Proposed Design

The scope of this project is to suggest ways of improving the safety and reliability of conversion systems while reducing conversion costs and time. Improvements to the performance of the systems was not directly in the scope of this project but was of course considered. This is also the subject of on-going efforts by the various gas utilities and has been studied in the past by B.C. Research [3,4].

This project does not investigate CNG storage tanks nor pressure relief devices as these are the objects of parallel research efforts sponsored by the Canadian Gas Association.

The design of refuelling probes has also been omitted. Similar research efforts by the CGA are focusing on two specific prototypes. However, this design has allowed for these new refuelling probes.

3.0 PROBLEMS IN CURRENT SYSTEMS

Several problems exist with current NGV system installations. Some of the fuel system components are not well placed in the vehicle, the fittings presently in use can leak, the number of fittings and connections is high and refuelling rate is slower than gasoline, and can be quite slow when filling more than three tanks.

According to Ron Bright, Ford of Canada's Director of Environmental Control and Vehicle Safety, the areas of a vehicle most frequently damaged in collisions are the corners and the extreme front and rear, the front more often than the rear [5]. The refuelling port, the back check valve and the manual shut-off valve are usually found under the hood on the front wheelwell (Figure 3). The pressure regulator is also often located on the wheelwell (Figure 2). The automatic fuel shut-off solenoid is found near the pressure regulator. Although the safety record of canadian NGV fuel systems is excellent, the high pressure components of the fuel system are generally located near these high risk areas, and could potentially be damaged in the event of a collision.

The high pressure line carrying fuel from the storage tanks to the engine must be carefully routed. At present, as there are no strictly reinforced guidelines for the routing of the high pressure fuel lines, there is the possibility that they may pass through one of the high risk areas. Figures 3 and 4 show a recent (1986) installation from a certified shop. It can be seen that the high pressure fuel line is routed across the top of the radiator, dangerously close to the front of the vehicle.

Since the refuelling port is no longer equipped with a vehicle disablement switch (a switch designed to ensure the ignition system is interrupted during refuelling), the engine may be running while the storage tank is being refilled. This is not a problem unless the refuelling port is under the hood, in which case a spark from the starter or the engine could possibly ignite any gas escaping from the refuelling operation should a leak occur. In February, 1985, a police car in Englewood, Colorado caught fire under these conditions [6].

Leaks in the natural gas fuel system usually occur where connections are made. First, the compression fittings used on the stainless steel fuel lines are difficult to seal if used by an inexperienced installer. Second, the pipe thread used for the screw-on fittings does not provide a mechanical seal, meaning a sealant must be used on the threads. There appears to be no sealants available on the market which are properly rated for the conditions encountered in natural gas fuel systems [2]. Sealants can lead to additional problems, if they get into the fuel lines, by interrupting the normal functioning of valves and fittings. Other types of sealants can dry up and cause leaks.

The number of fittings in most NGV conversions could be reduced while maintaining the integrity of the fuel system. Each extra fitting represents an unnecessary cost and increases the possibility of leaks. A rearrangement of the fuel system components could reduce the number of fittings required.

The time required to refuel a natural gas vehicles is typically longer than for a gasoline vehicle. This problem is aggravated if many vehicles or many tanks are being refuelled at once. A study has been undertaken by B.C. Hydro and B.C. Research to investigate the refuelling process. It is believed that the size of the refuelling line and restrictions in the tank valves inhibit the quick passage of natural gas to the tank(s). However, restrictions in the compressor station refuelling lines may be a major cause of slow refuelling.

4.0 IMMEDIATE SOLUTIONS: SHORT-TERM DESIGN

The goal of this section is to point out changes to NGV system installations that can be implemented immediately. These changes will simplify the fuel system, speed up refuelling, increase safety, and reduce the number of fittings and components. All suggestions fall within the standards of the Natural Gas Installation Code as prescribed by the Canadian Gas Association.

First, the refuelling port could be located on the exterior of the vehicle, as near to the storage tanks as possible. This would simplify refuelling and, because the tanks are located near the core of the vehicle, would serve to place the refuelling port in a position less likely to be damaged in the event of a collision. Also, placing the port far from the engine eliminates the spark hazard for any gas leaked during refuelling. The port could be rigidly mounted in one of three ways:

1) Alongside the gasoline port, i.e. in the same compartment, if space permits.
2) In a separate, recessed and covered mounting accessible through an exterior body panel (see Appendix A). The filler neck would be rigidly mounted via a bracket or other mounting device.
3) On a bracket underneath the vehicle body, i.e. on large trucks where the storage tanks are on the underbody. The refuelling port would be protected from road hazards.

In each case, the refuelling probe would have to withstand the specified forces involved for the break-away requirements.

Second, the back check valve should not be located alongside the refuelling port. Instead, it should be threaded into the first shut-off valve in the valve and tank assembly. This would ensure that the high pressure line between the check valve and the storage tanks is as short as possible and that the high pressure section does not extend to the perimeter of the vehicle.

Third, the stainless steel line from the refuelling port to the storage tanks could be increased to 3/8 in. from 1/4 in. diameter. This may speed up refuelling significantly. The work by B.C. Hydro and B.C. Research will investigate this possible scenario. Difficulties encountered routing the larger tubing

would be minor because of the short length of the refuelling line in the proposed design. It should be noted that 3/8 in. tubing will require the appropriate size fittings and back check valve.

Fourth, the storage tanks, if there are more than one, could be connected in series. Each tank would be equipped with a pressure relief device and a 'tank valve' with a 3-way shut-off, as presently available from Superior Valve Co. The first valve in the series would receive the inlet line from the refuelling port. The last valve in the series could effectively isolate the tanks and the refuelling system from the remainder of the fuel system, rendering a separate master shut-off redundant. To conform to the CGA regulations, the last valve in the series would have to be clearly marked as the "master" shut-off (see Figure 6). The series configuration would eliminate the need for a unique master shut-off and one tee joint in the high pressure line.

Fifth, the automatic fuel shut-off solenoid should be located near the storage tanks, as advocated by Tison et al [7]. It should be placed in the fuel line, directly downstream of the tanks' manual shut-off valves. This would limit the length of the high pressure line to several inches (from the tanks to the last valve) when the engine is not operating on CNG and when the engine is turned off. If the tanks are placed far apart in the vehicle, more than one solenoid should be considered. The ignition or vacuum switch which activates the solenoid should remain close to the engine and its connecting wire should run to the solenoid at the tanks. If it is necessary to include the solenoid in a sealed and vented bag, then the end of the solenoid with the electrical connection must extrude from the bag so that any leaking gas would not be ignited by an electrical spark. One disadvantage of moving the solenoid away from the regulator is that the time required to fully open the valve will increase [9]. This could cause problems during starting or fuel switch-over in which case the solenoid valve would have to be redesigned.

Sixth, the pressure regulator should be mounted on (when the firewall can support the regulator) or near the fire wall, or in a similar low risk area in the engine compartment. This would also ensure that the high pressure line from the storage tanks remains as far as possible from the perimeter of the vehicle while maintaining the short length required for the low pressure

line to the mixer/carburetor. The limited space on vehicle fire walls may necessitate fabricating a three-point bracket for the pressure regulator (see Appendix B).

Seventh, if the location of the tanks and valves dictates that a gas-tight enclosure (sealed bag) be used as a precaution against leaks, then the venting of this enclosure should not be to the underside of the vehicle. Natural gas, because it is lighter than air, would be more effectively vented upwards. This may be impractical, however it should be done whenever feasible. The vent could possibly coincide with the refuelling port on the exterior of the vehicle.

Lastly, the high pressure fuel line from the storage tanks to the pressure regulator should be routed to follow either the gasoline fuel line or the brake line. This would guarantee that a safe path is followed since car manufacturers are required to route these lines through the safest regions of the vehicle. The high pressure line should be one uninterrupted piece from the automatic shut-off to the pressure regulator in order to reduce the number of fittings and the likelihood of leaks.

A layout of the NGV fuel system, incorporating these solutions, is shown in Figures 5 and 6.

5.0 LONG-TERM DESIGN

It may not be possible to implement the following ideas immediately, however they should be considered for the future.

First, the pipe thread connections on the tanks and valves could be replaced by straight-thread, O-ring connections so that a sealant, i.e. Teflon tape, is not required. This will enable a good seal to be maintained after repeated refastening of the connections and eliminate the possibility of sealant entering the system. The high cost of such connections may be prohibitive. A more realistic scenario may be to encourage research into better sealants suited for NGV operation.

Second, safety could potentially be improved by the use of special tamper-proof fittings (e.g. special socket heads) or decals under the hood or at the connections warning that only qualified personnel should work on the system. This would deter unqualified persons from unknowingly removing vital components without taking the necessary precautions but is unlikely to prevent vandalism. Since special fittings are an expensive proposition, adequate warning and better training may be the best way to avoid errors.

Third, valves should be designed to allow a freer flow of gas. The valves presently in use are restrictive in size and in flow path. To pass in or out of a tank, the gas must travel through a mere 1/8" diameter passage in the valve and make a sharp 90 degree turn. A better design would speed up refuelling and may reduce the possibility of hydrate formation. This will be investigated in the joint project by B.C. Hydro and B.C. Research on refuelling station design.

Fourth, an ideal system would have all high pressure components confined to a single restricted area. This could be achieved by locating a pressure regulator at the storage cylinders and reducing the line pressure to about 40 psi. In the engine compartment, the 40 psi gas would be fed to the engine through a metering system. The high pressure components like the regulator, solenoid and master shut-off would be integrated into one unit located at the storage tanks. (This would also eliminate the need to redesign the solenoid valve as mentioned in the previous section). This proposition involves rerouting engine

coolant lines to the back of the vehicle to prevent regulator freeze-up. Also, the 40 psi. lines would have to be larger in diameter to provide sufficient flow rates without substantial pressure losses. A low pressure fuel system would reduce the potential for leaks and a light gauge flexible tube could be used to simplify installation. The gas metering system would have to compensate for the variations in line pressure due to varying flow rates. Such metering systems are conceivable using Generation II technology [9]. It would not be practical to do this on present Generation I systems, where the regulated dispensing pressures are 1-2 psi, because of engine tuning and response problems. If the proposed systems is considered, the authors recommend that tests be done to assess its safety relative to present systems under conditions of direct impact or vehicle crash.

Finally, the following recommendations from B.C. Hydro [2] were found valid and are presented. The use of stainless steel should be made mandatory for natural gas fuel systems. It has been their experience that carbon steel fuel lines corrode under normal operating conditions. B.C. Hydro are presently defining their own requirements which will include leak checking the conversion system 30 days after it is installed and more frequent shop inspections.

6.0 CONCLUSIONS

A number of suggestions were made in this report for improving the safety, reliability and simplicity of natural gas fuel systems. The major short term solution involved placing the refuelling line close to the storage tanks and thus eliminate underhood refuelling. The long term solutions are aimed at localizing the high pressure areas near the tanks but it is recognized that more research is needed to assess the relative safety of such a move. Finally, it should be noted that the suggestions will lead to better NGV fuel systems only if the regulations are enforced more strictly. This could be done by more frequent conversion shop inspections as suggested by B.C. Hydro. In some instances, the B-149 code should be clarified to avoid some of the problems described in this report.

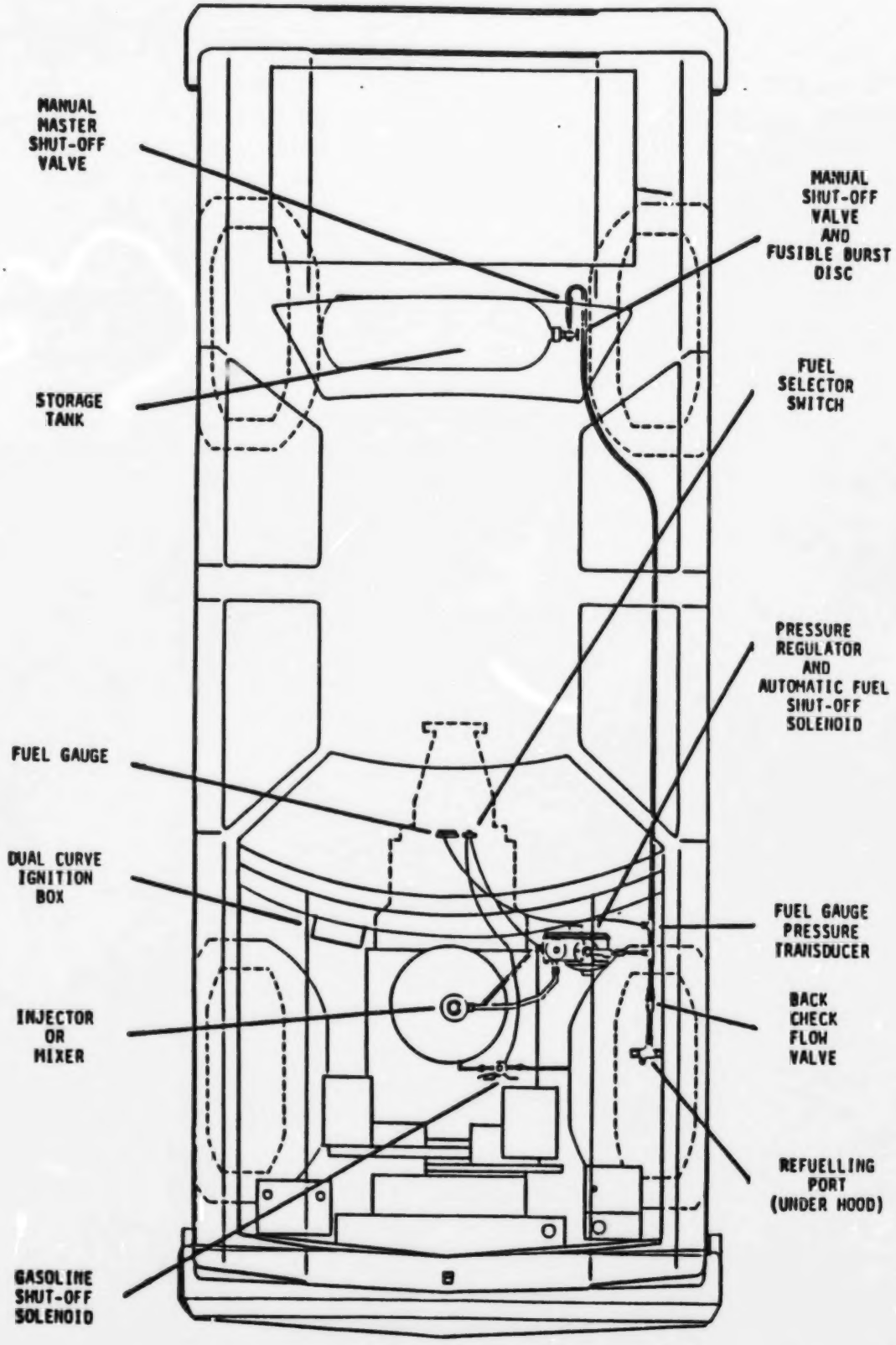


Figure 1. Typical Fuel System Layout

Vehicle #1

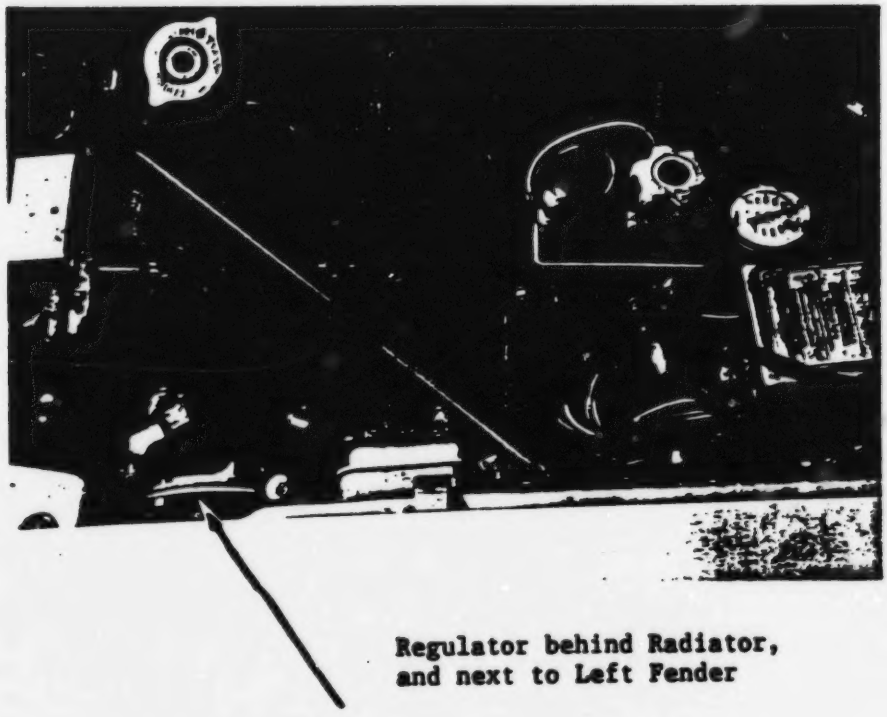


FIGURE 2
Photograph of a Typical Pressure
Regulator Installation

Vehicle #2

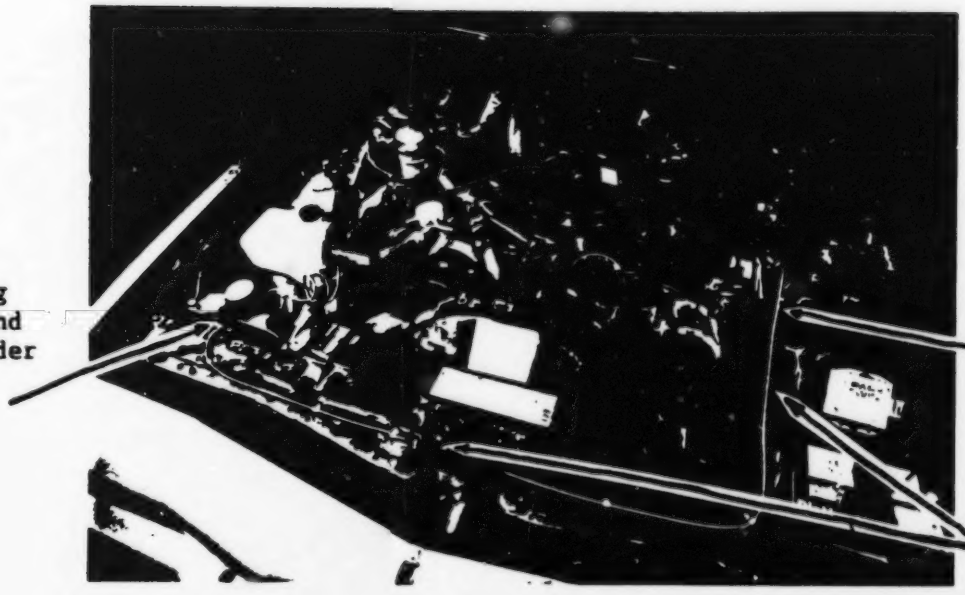


FIGURE 3
Photograph of a Typical Fuel System
Installation in Engine Compartment

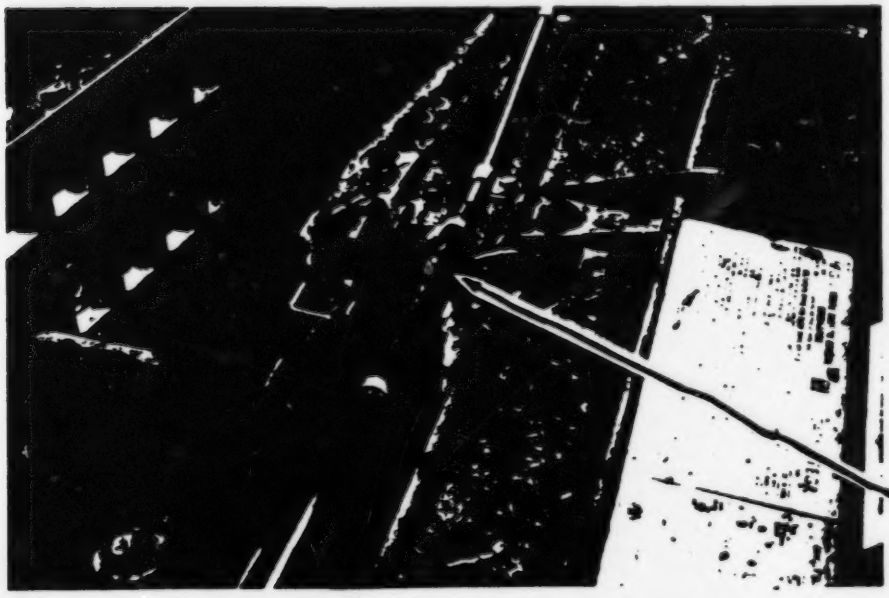


FIGURE 4
Close-up Photograph of the Refuelling Line

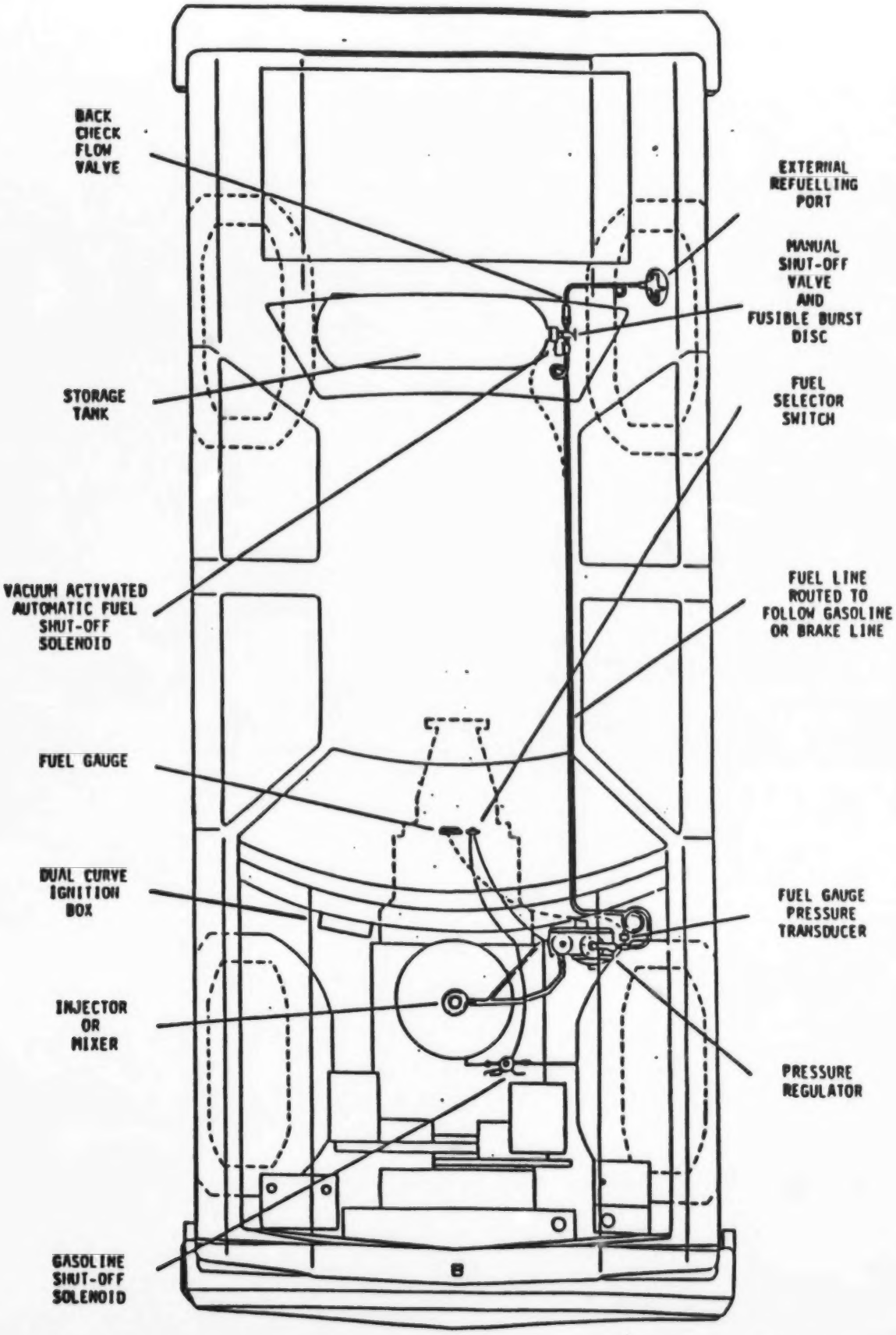

BACK CHECK FLOW VALVE
EXTERNAL REFUELLING PORT
MANUAL SHUT-OFF VALVE AND FUSIBLE BURST DISC
STORAGE TANK
FUEL SELECTOR SWITCH
VACUUM ACTIVATED AUTOMATIC FUEL SHUT-OFF SOLENOID
FUEL LINE ROUTED TO FOLLOW GASOLINE OR BRAKE LINE
FUEL GAUGE
DUAL CURVE IGNITION BOX
FUEL GAUGE PRESSURE TRANSDUCER
INJECTOR OR MIXER
PRESSURE REGULATOR
GASOLINE SHUT-OFF SOLENOID

FIGURE 5 Proposed NGV Fuel System Layout

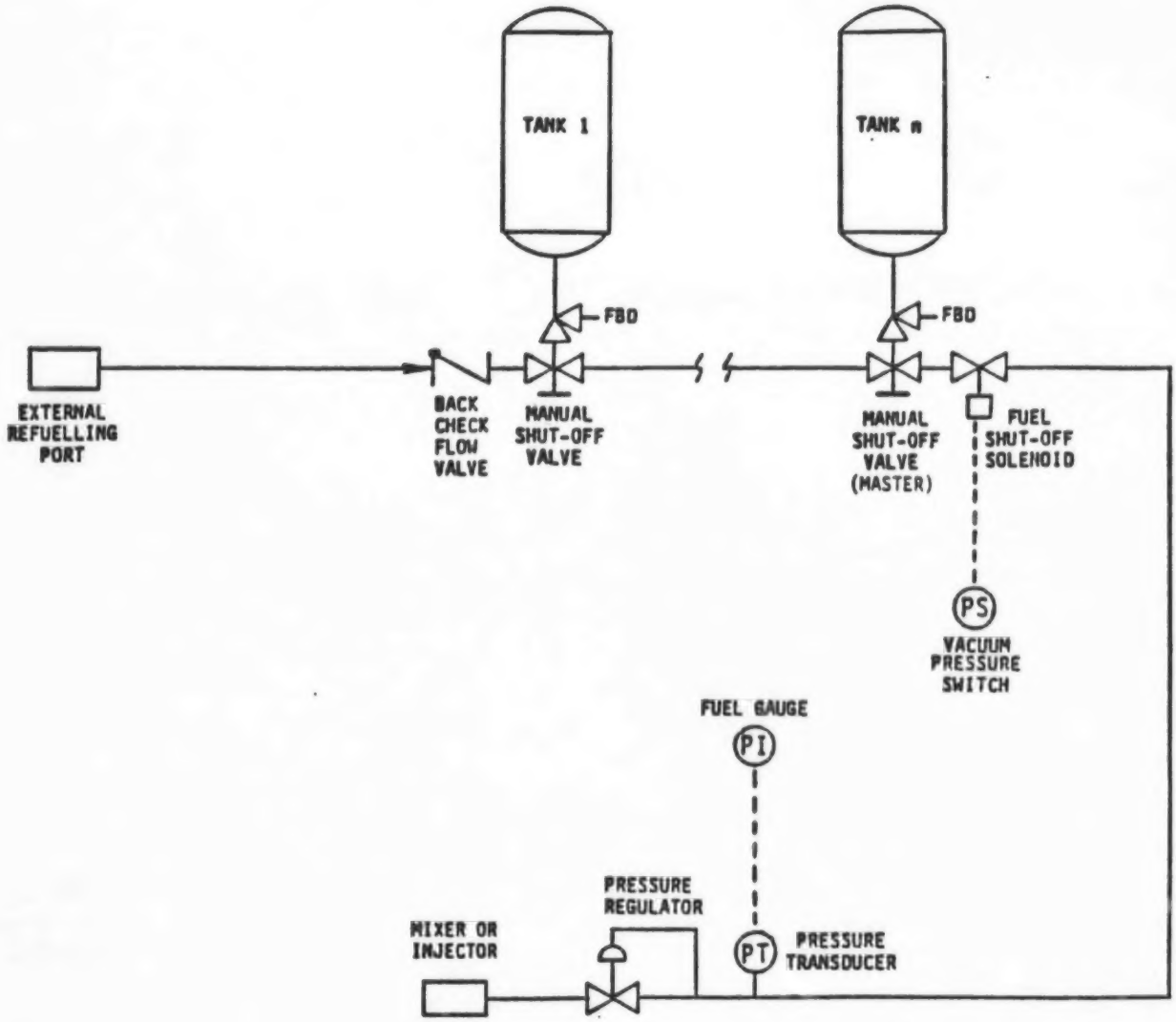


FIGURE 6 Schematic of Proposed Fuel System

7.0 REFERENCES

[1] Ontario Natural Gas Association, "Ontario Utilities Specification for Natural Gas/Gasoline Vehicle Conversions", Number NGV-001-1985-07-03

[2] B.C. Hydro Gas Division, Comments on report and conversations with Bill Hennessey, June 29, 1987.

[3] Evaluation of Currently Available Compressed Natural Gas Conversion Equipment, B.C. Research, Report nb. C 0233, 1983.

[4] Compressed Natural Gas Conversion Kit Performance Testing, B.C. Research, Report no. C 0237, 1983.

[5] Private Communication with Ron Bright, Ford of Canada, January 1987.

[6] Lewis, G. J., "Report on Findings at City of Englewood", Total Fuels, Inc. release, February 25, 1985.

[7] Tison, R.R., Sprafka, R.J., Bechtold, R.L., and Timbario, T.J. "Safety Issues Surrounding the Use and Operation of Compressed Natural Gas Vehicles", SAE Technical Paper 831078, 1983.

[8] Private Communication with Patrick Brown, Patrick Brown Systems Ltd., February 2, 1987.

[9] Private Communication with Steve Carter, CNG Fuel Systems Ltd, February 19, 1987.

[10] Veart, A. and Harris, G., "Introduction of CNG in New Zealand", Proceedings of the 1986 International Conference of the S.A.E. - Australasia Inc., 1986

[11] Crashworthiness of NGV Fuel System Components, B.C. Research, Report nb. C0468,1984.

[12] Low Temperature Durability of Valve Bagging and Gas Barrier Material for Natural Gas Fuelled Vehicles, B.C. Research Report nb. C 0742, 1985.

[13] Consumers Gas, Comments received and discussions with Michael Grant, January and February 1987.

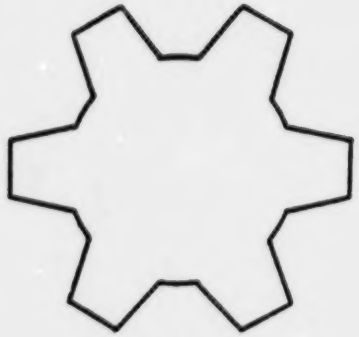
APPENDICES

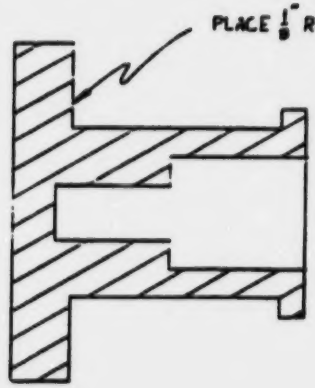
APPENDIX A - External Refuelling Port

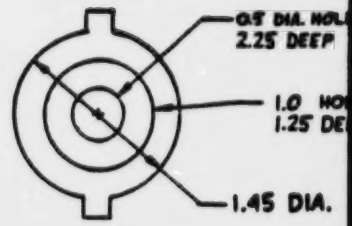
The external refuelling port design consists of a mount for the fuel receptacle and a cap to protect the receptacle from the elements (see figure). Both components would be molded out of polycarbonate plastic. Molding costs are in the order of $6000-10000. Each component would cost approximately $1 to produce after the molding cost.

The refuelling port mount should be located on a rear quarter panel of the vehicle, as far forward and as close to the storage tanks as is practical. It would be held flush to the body panel by a U-clip similar to those used to hold dashboard instruments in place. The U-clip would be fastened by an extra nut on the threaded male end of the refuelling receptacle.

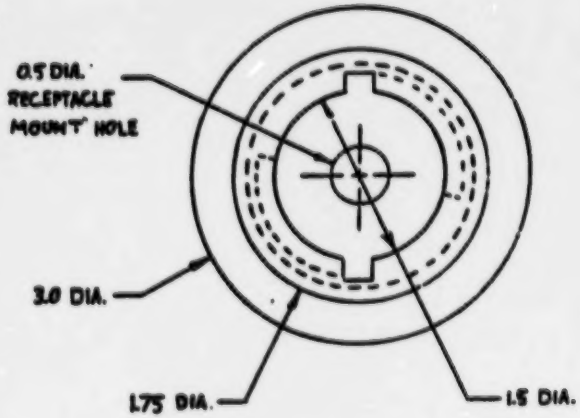
The cap will close by lining up the tabs with the grooves on the mount, inserting the cap until the rubber washer is compressed, and rotating the cap clockwise 1/4 turn.

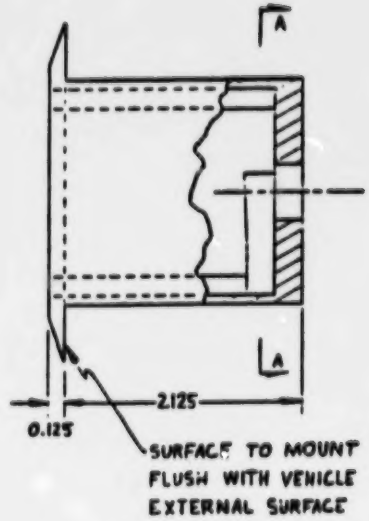


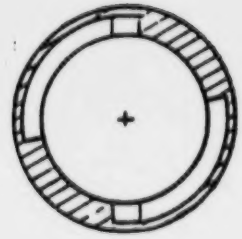




REFUELLING PORT CAP





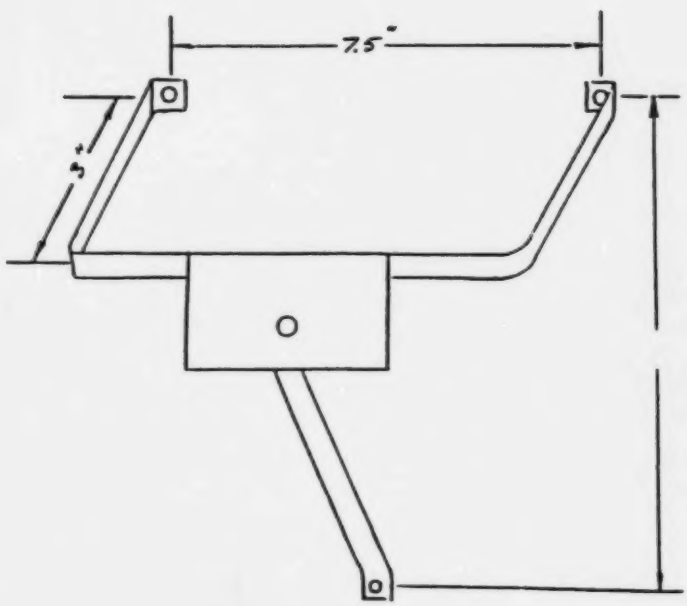


VIEW A-A

REFUELLING PORT MOUNT

APPENDIX B - Mounting Bracket

This bracket could be used if there is limited space on the firewall of the vehicle. The dimensions given allow the regulator to be mounted over top of the dual curve ignition box. Because of the shape of the pressure regulator, care should be taken when using this bracket so that the regulator does not contact the vehicle's hood when in the closed position. The bracket is three-point to minimize the effects of vibration.



Pressure Regulator Bracket